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(54) Cantilever type probe, scanning tunnel microscope and information processing apparatus using the same

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(56) References cited:
WO-A-89/07258 US-A- 4 880 975

- REVIEW OF SCIENTIFIC INSTRUMENTS. vol. 58, no. 8, 1 August 1987, NEW YORK us pages 1343 - 1348; B.L.BLACKFORD ET AL: 'HIGH STABILITY BIMORPH SCANNING TUNNELING MICROSCOPE'
- IEEE ELECTRON DEVICE LETTERS. vol.10, no. 11, 1 November 1989, NEW YORK us pages 490 - 492; S.AKAMINE ET AL: 'MICROFABRICATED SCANNING TUNNELING MICROSCOPE'
- PHYSICAL REVIEW LETTERS vol. 49, no. 1, 5 July 1982, pages 57 - 61; G.BINNIG ET AL: 'SURFACE STUDIES BY SCANNING TUNNELING MICROSCOPE'

Description

The present invention relates to a cantilever type probe used in a scanning tunnel microscope (STM) and an information recording and reproducing apparatus utilizing the principle of scanning tunneling microscopy.

The present invention also relates to a scanning tunnel microscope and an information processing apparatus which can perform recording, reproducing and erasing of information.

Recently, there has been developed a scanning tunnel microscope with a resolving power on the atomic or molecular order. The concept of STM has been applied to analyze surface structures and to measure surface roughness and the like.

The scanning tunnel microscope (hereinafter abbreviated as STM) is based on the phenomenon that tunnel current changes exponentially dependent upon the distance between a conductive probe and a conductive specimen when they are made to approach each other at a distance of about 1 nm with a voltage applied therebetween.

An image of the surface of a specimen can be obtained utilizing the change of tunnel current caused by the atomic arrangement or uneven structure of the surface of the specimen when a probe, which has a very sharp tip formed by electrolytic polishing and the like, is scanned two-dimemsionally while keeping the distance between the probe and the surface of the specimen, which comprises conductive material, constant [G. Binnig et al., Phys. Rev. Lett. Vol 49 (1982) 57]. Moreover, there has been proposed an apparatus capable of high density recording and reproduction by utilizing the principle of STM and a medium which has a surface having a fine, uneven structure or with electrically different portions.

In such an apparatus, it is necessary to scan the specimen using a probe in a range of several nm to several μm. A piezoelectric element is used as a moving mechanism. As examples of such a moving mechanism, there are the tripod type and the cylindrical type. The Tripod type mechanism is one which combines three piezoelectric elements which are perpendicular to each another along the x, y and z directions and a probe which is located on the intersecting point of the three elements.

A cylindrical type mechanism utilizes one end having divided electrodes provided around the peripheral surface of a cylindrical piezoelectric element. A probe is provided on the other end of the divided electrodes which is able to scan, which makes the cylinder bend corresponding to each divided electrode.

Lately, attempts have been made to form a fine cantilever type probe by employing micromechanical techniques utilizing semiconductor processing.

Fig. 12 shows an example of a prior art piezoelectric bimorph cantilever formed on a silicon (Si) substrate by employing a micromechanical technique in accordance with the Proceedings of 4th International Conference on STM/STS, page 317.

Fig. 12(a) is a perspective view of such a cantilever.

The cantilever is formed on a silicon substrate by laminating divided electrodes 4a and 4b, ZnO piezoelectric material 5, common electrode 3, ZnO piezoelectric material 5 and divided electrodes 2a and 2b in this order, followed by removing a part of the silicon substrate under the cantilever by anisotropic etching.

The metal probe 7, which is provided on one end of the piezoelectric bimorph cantilever by adhering or the like, can detect tunnel current through a drawing electrode 6.

Fig. 12(b) is a sectional view of the cantilever. The cantilever can be moved three-dimensionally and independently by controlling voltages applied on four regions of piezoelectric material which comprise two regions sandwiched between upper divided electrodes 2a and 2b and common electrode 3 and two regions sandwiched between lower divided electrodes 4a, 4b and common electrode 3.

Fig. 13 (a), (b) and (c) are illustrations showing motions of a prior art cantilever in driving by changing combinations of regions to which voltages are applied within four regions of piezoelectric material divided by pair of divided electrodes.

Fig. 13(a) shows the motion of a cantilever which can move probe 7 toward the y-direction shown in Fig. 12(a) when voltages with the same phase are applied so that four regions can contract simultaneously. Fig. 13 (b) shows the motion of a cantilever which can move probe 7 toward the x-direction shown in Fig. 12(a) when an upper and lower region in the right side in Fig. 13(b) stretch and an upper and a lower region in the left side contract. Fig. 13(c) shows the motion of cantilever which can move probe 7 toward the z-direction shown in Fig. 12(a) when a right and a left region in the upper side contract and a right and a left region in the lower side stretch.

In the prior art, however, there is been a problem in that noise, due to the presence of control voltages, is induced in probe 7 and drawing electrode 6, because the drawing electrode 6 for probe 7 is placed adjacent to the driving electrodes of the piezoelectric bimorph. Accordingly, noise is superimposed on the fine tunnel current detected, which makes it difficult to obtain precise STM images.

Moreover, in the prior art, there has been a problem that when the probe 7 runs into a sample surface it may be damaged because a feedback control signal for maintaining the distance between the probe and sample is subject to the superimposed noise.

WO-A-8907258 discloses a scanning tunnelling microscope including an integrated piezoelectric transducer of the type acknowledged above as prior art.

Accordingly, an object of the present invention is to provide a cantilever type probe capable of reliably detecting information without receiving noise caused by control voltage applied to the driving electrodes of a pi-

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ezoelectric bimorph structure, an information processing apparatus and a scanning tunnel microscope using the same.

According to the present invention there is provided a cantilever probe comprising a piezoelectric bimorph cantilever comprising piezoelectric material provided between driving electrodes for driving the cantilever, a probe formed on the cantilever, and a drawing electrode for the probe formed on the cantilever;

characterised in that:

a shielding electrode is provided on the cantilever for electrically isolating the drawing electrode and the probe from the driving electrodes, and

means are provided for earthing the shielding electrode.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 (a) is a perspective view of a cantilever type probe of Example 1 and Fig. 1(b) is a sectional view thereof;

Fig 2 is a perspective view of a cantilever type probe of Example 2;

Fig. 3(a) is a perspective view of a cantilever type probe of Example 3 and Fig. 3(b) is a sectional view therof;

Fig.4 is a view illustrating a driving method of a cantilever type probe of Example 3;

Fig. 5(a) is a perspective view of a cantilever type probe of Example 4 and Fig. 5(b) is a sectional view thereof;

Fig. 6 is a perspective view of a cantilever type probe of Example 5;

Fig. 7(a) is a perspective view of a cantilever type probe of Example 6 and Fig. 7(b) is a sectional view thing;

Fig. 8 is a view showing a process for making a cantilever type probe shown in Fig. 7;

Fig. 9 is a schematic diagram of electrodeposition apparatus used in forming a cantilever type probe Fig. 7;

Fig. 10 is a schematic diagram of STM using a cantilever type probe of the present invention;

Fig. 11 is a schematic diagram of recording and reproducing apparatus using a cantilever type probe of the present invention;

Fig. 12(a) is a perspective view of a cantilever type probe of the prior art and Fig. 12(b) is a sectional view thereof; and

Fig. 13(a) to (c) are views showing motions of a conventional cantilever type probe.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to the present invention, it is possible to reduce noises induced in a probe and a drawing electrode from driving electrodes and to detect tunnel current with higher signal to noise ratio (S/N) by providing a shielding electrode for electrically isolating driving electrodes from the probe and the drawing electrode contained in a cantilever type probe comprising a cantilever (elastic beam member) a probe and a drawing electrode formed thereon.

The following examples are illustrative only and typify certain preferred embodiments. Other aspects of the invention will be apparent to those skilled in the art.

Example 1

As shown in Figs. 1a and 1b, a cantilever type probe comprises a piezoelectric bimorph cantilever, one end of which is fixed on Si substrate 1 and a probe 7 is formed on the other free end of the cantilever. The piezoelectric bimorph layer comprises (i) divided electrodes 2a and 2b, (ii) piezoelectric layer 5, (iii) common electrode 3, and (iv) divided electrodes 4a and 4b.

Each of the electrodes extends to a fixed end of the cantilever where pad portion 13 is provided and is combined with an external driving circuit by wire bonding and the like at pad portion 13.

The piezoelectric material includes materials such as ZnO, AlN and the like. These materials can form a film oriented to the c-axis by using magnetron sputtering. The piezoelectric material can be formed using piezoelectric ceramics, such as PZT (Pb(lead) zirconate titannte) and the like. Electrodes are formed by vacuum evaporation using material such as Al, Au, Cr and the like.

A shielding electrode is formed on divided electrodes 2a and 2b of the piezoelectric bimorph layer through an insulating layer 10. Probe 7 and drawing electrode 6 are formed thereon through the insulating layer 10. The insulating layer 10 is formed by vacuum evaporation using SiO_2, Si_3N_4 and the like and probe 7 is formed by adhering a small piece of material such as Pt, Pt-Rh alloy, Pd, W, TiC and the like.

To form the entire cantilever one may form an electrode by vacuum evaporation of silicon. By alternately patterning and sputtering piezoelectric material a piezoelectric bimorph is formed on the Si substrate. An insulating layer 10, a shielding electrode 11 and an insulating layer 10 on divided electrodes 2a nd 2b is formed ther-

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eon. By vacuum evaporation of drawing electrode 6 and patterning and removal of unnecessary portions of the Si substrate by anisotropic etching, the piezoelectric bimorpn is configured in the form of a beam.

The function of shielding electrode 11 is explained using Fig. 1(b).

A piezoelectric bimorph which comprises electrodes 2a, 2b, 3, 4a and 4b and a piezoelectric material 5 is oriented to c-axis in the direction which the piezoelectric material 5 is laminated. Common electrode 3 is connected to ground and driving voltages V_2a, V_2b, V_4a and V_4b are applied to divided electrodes 2a, 2b and 4a, 4b.

By combinations of stretching and contracting in four regions sandwiched between two divided electrodes and the common electrode, the piezoelectric bimorph bends, stretches and contracts. Therefore, probe 7 can independently be driven in the x, y and z direction. In STM, images are obtained by applying a bias voltage between a sample and a probe, detecting tunnel current flowing therebetween and controlling the distance therebetween, based on a value of the tunnel current.

Using a conventional driving mechanism for controlling the distance between probe and sample causes noise between probe 7 and drawing electrode 6 because irregular controlled voltages are applied to divided electrodes 2a, 2b, 4a and 4b of the piezoelectric bimorph.

On the other hand, in the present invention, it is possible to remarkably reduce the noise by providing a shielding electrode 11 between divided electrodes 2a and 2b and probe 7 and drawing electrode 6 of the piezoelectric bimorph and keeping the shielding electrode at ground potential.

Example 2

The second embodiment of the present invention is illustrated below.

Fig. 2 shows a cantilever type probe which comprises probe 7 and drawing electrode 6 provided directly on piezoelectric material 5 between divided electrodes 2a and 2b of the piezoelectric bimorph and shielding electrodes 11 are provided between drawing electrode 6 and divided electrodes 2a and 2b.

Common electrode 3 of the piezoelectric bimorph is kept at ground potential in the same manner as in Example 1 and shielding electrodes 11, 11 which are provided at both sides of drawing electrode 6 are also kept at ground potential. Therefore, it is possible to reduce noise induced by driving voltages applied to divided electrodes 2a and 2b.

This structure of the piezoelectric bimorph facilitates production because the number of electrode layers and insulating layers is reduced.

Example 3

As shown in Fig. 3, another embodiment of the cantilever type probe comprises a piezoelectric bimorph cantilever, one end of which is fixed on Si substrate 1, and probe 7 is formed on the other end of the cantilever.

The piezoelectric bimorph comprises common electrode 3, piezoelectric material 5, divided electrodes 2a and 2b, piezoelectric material 5 and divided electrodes 4a and 4b. Each of the electrodes extends to a fixed end of the cantilever where pad portion 13 is provided, and is combined with external driving circuit by wire bonding at pad portion 13.

The piezoelectric material which is employed includes ZnO, AlN and the like. These materials can form a film oriented to the c-axis by magnetron sputtering. The piezoelectric material can also be formed using a piezoelectric ceramic such as PZT. Useful electrode material includes Al, Au, Cr and the like and electrodes are formed by vacuum evaporation.

An insulating layer 10, including SiO2 or Si_3N_4, is provided on common electrode 3 of the piezoelectric bimorph and drawing electrode 6 and probe 7 are provided thereon. Probe 7 is formed by adhering a small piece of electroconductive material such as Pt, Pt-Rh alloy, Pd, W, TiC and the like.

To produce the entire cantilever one can employ an alternate repetition of vacuum evaporation of electrode and patterning, and sputtering of piezoelectric material and patterning to form a piezoelectric bimorph on the Si substrate and removal of unnecessary portions of the Si substrate by anisotropic etching so as to leave the piezoelectric bimorph in the form of a beam. Next, motions and driving method of the cantilever type probe are explained below.

As shown in Fig. 3(b), where piezoelectric material 5 is formed by magnetron sputtering, the piezoelectric material is film-formed in such a manner that c-axis direction is equal to the direction of the film thickness, as shown with the vertical arrow. Therefore, piezoelectric material 5 can contract or stretch in the direction perpendicular to the c-axis according to plus and minus direction of electric field applied toward the c-axis direction of the piezoelectric material 5.

Four regions of the piezoelectric material which are sandwiched between common electrode 3 and divided electrodes 2a and 2b and 4a and 4b, can stretch or contract in the direction perpendicular to the c-axis by changing the direction of electric field applied between electrodes. By that combination, the piezoelectric bimorph bends in the x and z directions and stretches or contracts in the y direction. Therefore, probe 7 is driven in the x, y and z directions.

Fig. 4 shows a circuit which applies driving voltages to each of the electrodes of the piezoelectric bimorph and a combination of the driving voltages. In Fig. 4, 21 and 22 denote adders having single gain, 23 and 24 denote adders having double gain and 25 denotes inverter.

In this driving method, common electrode 3 is always kept at ground potential so that driving voltages applied to divided electrodes 2a and 2b and 4a and 4b are not induced as noise toward probe 7 and drawing electrode 6.

Herein, in order to drive probe 7 in the x direction, it is necessary to apply voltage -Vx to electrode 2a so as to have potential difference -Vx between common electrode 3 and electrode 2a, and to apply voltage -2Vx to electrode 4a so as to have potential difference -Vx between electrode 2a and electrode 4a. Similarly it is necessary to apply voltage Vx to electrode 2b and to apply voltage 2Vx to electrode 4b. By doing so, the right side of piezoelectric material sandwiched between common electrode 3 and electrodes 2a, 4b contracts and the left side of the piezoelectric material sandwiched between common electrode 3 and electrodes 2b, 4b stretches. In this manner, the piezoelectric bimorph bends in the x direction shown in Fig. 4.

Once a voltage Vx for driving probe 7 in the x direction is applied to a circuit, voltage Vx is applied to electrode 2b through adder 21, voltage -Vx is applied to electrode 2a through inverter 25 and adder 22, voltage 2Vx is applied to electrode 4b through double adder 23, and voltage -2Vx is applied to electrode 4a through inverter 25 and double adder 24.

In order to drive probe 7 in the y direction, it is necessary to apply voltage Vy to electrode 2a, 2b so as to have potential difference Vy between common electrode 3 and electrodes 2a, 2b, and to apply voltage 2Vy to electrodes 4a, 4b so as to have potential difference Vy between electrodes 2a, 2b and electrodes 4a, 4b. By doing so, the piezoelectric material sandwiched between each electrode is stretched by the same amount, and therefore, the piezoelectric bimorph stretches in the y direction.

In order to drive probe 7 in the z direction, it is necessary to apply voltage -Vz to electrodes 2a, 2b so as to have potential difference -Vz between common electrode 3 and electrode 2a, 2b, and to apply voltage (-Vz + Vz = 0) to electrodes 4a, 4b so as to have potential difference Vz between electrodes 2a, 2b and electrodes 4a, 4b. By doing so, the upper side of the piezoelectric material sandwiched between common electrode 3 and electrodes 2a, 2b contracts and the lower side of the piezoelectric material sandwiched between electrodes 2a, 2b and electrodes 4a, 4b stretches. Therefore, the piezoelectric bimorph bends in the z direction shown in Fig. 4. By adding each of the driving voltages Vx, Vy and Vz to adders 21, 22, 23 and 24 and applying each of driving voltages to each electrodes 2a, 2b, 4a and 4b, probe 7 can be driven simultaneously in x, y and z direction.

Example 4

As shown in Fig. 5(a), in this embodiment the cantilever comprises a piezoelectric bimorph, one end of which is fixed on substrate 1, and a probe 7 formed on the free end of the cantilever. The cantilever has a structure which comprises a protective layer 12, the third pair of divided driving electrodes (4a, 4b), a piezoelectric layer 5, the second pair of divided driving electrodes (3a, 3b), a piezoelectric layer 5 and the first pair of divided driving electrodes (2a, 2b). Each of the electrodes extends to a fixed end of the cantilever where a pad portion is provided, and is combined with external driving circuit by wire bonding and the like at pad portion 13. Moreover, a drawing electrode 6 is provided in the same plane where the first divided driving electrodes are provided, and a probe 7 is provided on the drawing electrode 6.

A shielding electrode 11 is provided in the same plane where the second divided driving electrodes are provided. The shielding electrode 11 is placed so as to overlap with the drawing electrode 6 and the width of the shielding electrode is preferably larger than that of the drawing electrode 6. The width of the drawing electrode 6 may be any size providing it is possible to take out a signal current and may preferably be more than 5μm.

Substrate 1 includes a wafer of semiconductive crystal such as Si, GaAs and the like. Protective layer 12 includes Si_3N_4, SiO_2, amorphous Si-N-H and the like formed by Low Pressure Chemical Vapor Deposition (LPCVD) or plasma CVD. Materials of piezoelectric layer 5 include piezoelectric materials such as ZnO, AlN, $TiBaO_3$, PZT and the like. These materials are used such that crystals are oriented to the c-axis, perpendicular to the substrate.

C-axis orientation depends on the degree of crystallinity of driving electrodes 3a, 3b, 4a and 4b which correspond to base electrodes. Therefore, materials should be carefully selected. Materials having larger c-axis orientation may be preferred. Methods of forming this kind of film include sputtering (magnetron sputtering), chemical vapor deposition (CVD), physical vapor deposition (PVD) and the like. Materials of driving electrodes 2a, 2b, 3a, 3b, 4a and 4b include Au, Al, Cr, Mo, W, Ti, Cu and the like or a lamination of these materials.

Materials of shielding electrode 11 preferably include the same materials as that of the second divided driving electrodes 3a, 3b (except in a special case), because shielding electrode 11 is provided on the same plane as driving electrodes 3a, 3b.

Materials of drawing electrode 6 preferably include the same materials as that of the first divided driving electrodes 2a, 2b (except in a special case), because drawing electrode 6 is provided on the same plane as driving electrodes 2a, 2b.

Methods for forming electrodes include vapor evaporation by sputtering or electron beam, CVD and the like. Materials of probe 7, which is provided on drawing electrode 6, include Pt, Pd, W, TiC, Au, Cu, Cr, Si and the like.

Next, a process of producing the entire cantilever is briefly explained.

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Protective layer 12 is formed on Si substrate and the third driving electrode 4 is vapor-deposited, followed by dividing the driving electrode into two electrodes 4a, 4b using a photolithographic process.

Next, piezoelectric layer 5 is formed by magnetron sputtering method, followed by forming the second driving electrode 3 and shielding electrode layer 11 and forming electrodes 3a, 3b, 11 by dividing electrodes using a photolithographic process.

Piezoelectric layer 5 is formed thereon by a magnetron sputtering method, and the first driving electrode 2 and drawing electrode layer 6 are formed at the upper portion, followed by forming each of electrodes 2a, 2b and 6 using a photolithographic method. A material of probe 7 is deposited on the drawing electrode 6 and probe 7 is formed by a photolithographic method so as to make a probe of a desired height and shape. Finally, the piezoelectric bimorph is formed by removing unnecessary portions of the Si substrate by anisotropic etching so as to leave piezoelectric bimorph in a shape of a beam.

In this Example, a Si_3N_4 layer 5000 Å thick is formed on a wafer of Si substrate with (100) face by LPCVD, followed by providing an opening in the Si_3N_4 film on one side of wafer by reactive ion etching method using CF_4 photolithography.

A gold electrode 1000 Å thick and a ZnO layer 3000 Å thick are formed alternatively on the Si_3N_4 layer.

After depositing each layer, a pattern is formed using photolithography and etching to form a structure with the shape of the electrodes shown in Fig. 5(a). After the upper portion is protected by plasma depositing on a-Si:N:H film, the cantilever is formed by removing Si under wafer using anisotropic etching. After removing the upper protective film, a probe is provided on the tip portion of the cantilever to complete the desired cantilever type probe.

The motion of the cantilever type probe is explained using Fig. 5(b).

Piezoelectric bimorph which comprises driving electrodes 2a, 2b, 3a, 3b, 4a and 4b, and piezoelectric material 5, is oriented to x-axis in the direction which piezoelectric material 5 is laminated. Voltages V2a, V2b applied to the first divided driving electrodes 2a, 2b, which are located on the upper surface, are kept at ground.

Voltages V_{3a}, V_{3b} are applied to the second divided driving electrodes 3a, 3b which are located on the intermediate portion. Voltages V_4a, V_4b are applied to the third divided driving electrodes 4a, 4b which are located on the bottom surface. The same voltages as in Example 3 are applied to the second divided electrodes 3a, 3b and the third divided electrodes 4a, 4b.

Piezoelectric bimorph can bend, stretch or contract by a combination of stretching or contracting of four regions of piezoelectric material 5 which is sandwiched between the first divided driving electrodes 2a, 2b, the third divided driving electrodes 4a, 4b and the intermediate divided driving electrodes 3a, 3b. Therefore, probe 7 can be driven in the direction of x, y, z-axis, easily, independently and stably.

In STM, images are obtained by applying a bias voltage between a specimen and probe 7, detecting tunnel current flowing therebetween and controlling the distance therebetween.

When the piezoelectric bimorph is used as a driving mechanism for controlling the distance between a probe and a specimen, noises may be easily induced to probe 7 and drawing electrode 6 (which detect fine tunnel current), because irregular control voltages are applied to the second divided driving electrodes 3a, 3b and the third divided driving electrodes 4a, 4b of piezoelectric bimorph.

Therefore, by providing shielding electrode 11 between drawing electrode 6 and the third divided driving electrodes 4a, 4b, and keeping shielding electrode at ground, shielding electrode 11 works as shield with the first divided driving electrodes 2a, 2b and inducement of noises can be effectively reduced.

While keeping the first divided electrodes 2a, 2b and shielding electrode 11 at ground and flowing DC current of 10 nA to the probe, AC voltage with 5 to 10V is applied to the second divided driving electrodes 3a, 3b and the third divided driving electrodes 4a, 4b with change of frequency. As a result, current value in probe 7 is not affected by noises.

According to the present Example, a cantilever type probe can be easily produced without increasing the number of laminated layers.

Example 5

In this Example, a cantilever type probe is used, in which another shielding electrode 11′ is added to cantilever type probe used in Example 4, so as to sandwich drawing electrode 6 in the same plane as the first divided driving electrodes 2a, 2b and is kept at ground, as shown in Fig. 6.

In this case, the upper divided electrodes 2a, 2b are not necessarily kept at ground, because shielding electrode 11′ shields drawing electrode 6 and probe 7.

In this Example, when the space between drawing electrode 6 and shielding electrode 11′ is set to 1.5μm, the noise induced by the first divided driving electrodes 2a, 2b is completely reduced, a signal can be stably taken out and the cantilever with probe can be stably and independently scanned along the surface shape of the specimen.

Example 6

Fig. 7(a) is a perspective view of a cantilever type probe of another embodiment of the present invention and Fig. 7(b) is the sectional view in the A-A face.

In this Example, as shown in Fig. 7(a), the cantilever comprises a piezoelectric bimorph, one end of which is

fixed on the Si substrate and probe 7 is formed on the other end of the cantilever. The piezoelectric bimorph layer comprises divided electrodes 4a, 4b, piezoelectric layer 5, divided electrodes 2a, 2b, piezoelectric layer 5 and common electrode 3.

On the uppermost piezoelectric bimorph layer, insulating layer 10, drawing electrode 6, insulating layer 10 and shielding electrode 11 are formed. Piezoelectric bimorph is driven by keeping common electrode 3 at ground potential and by changing the voltage applied to divided electrode in the same manner as in Example 3.

This Example is characterized in that shielding electrode 11 is provided on the entire upper surface except the region in which probe 7 is provided. By this feature, probe 7 and drawing electrode 6 are surrounded by shielding electrode 11 and common electrode 3, and more complete shielding is possible.

A process of producing the entire cantilever includes the repetition of vapor evaporation of a bottom electrode and patterning on the Si substrate, and vapor evaporation of piezoelectric material by sputtering and patterning to form the piezoelectric bimorph, the repetition of vapor evaporation and patterning of the insulating layer, drawing electrode, insulating layer and shielding electrode.

Fig. 8(a) shows the structure of the cantilever obtained above. For simplicity, a part of the piezoelectric bimorph layer is omitted.
For this structure, resist R is provided by lithography (Fig. 8(b)), followed by removing a part of shielding electrode 11 by etching with potassium iodide (Fig. 8(c)). Then, a part of SiO_2 insulating layer 10 is removed with fluoric acid solution (Fig. 8(d)), followed by removing resist R (Fig. 8(e)).

Next, probe 7 is formed using an electrodeposition method. Fig. 9 is a schematic view of electrodeposition method used in this Example.

In Fig. 9, 14 denotes an electrode consisting of platinum 15 and 16 denote DC power supplys for electrodeposition and 17 denotes an ammeter. Drawing electrode 6 and shielding electrode 11 are respectively wired as shown in Fig. 9. Anode 14 consisting of Pt and cantilever portion are immersed in gold sulfite plating solution (trade name: Neutronecs 309, available from ELECTROPLATING ENGINEERS OF JAPAN LTD., Nihonbashi, Chuhoh-ku, Tokyo, Japan), followed by applying a voltage of about 1V to power supply 16 to adjust power supply 15 so as to provide a reading of 1 mA/Cm^2 in ammeter 17. In this manner, probe 7 is formed.

After conducting the steps described above, an unnecessary portion of Si substrate is removed by anisotropic etching to form the cantilever type probe.

STM image is observed using this type of cantilever type probe. As a result, a clear image with little noise is obtained.

Example 7

Scanning Tunnel Microscope (STM) using a cantilever type probe described in one of Example 1 to 6 is explained herein.

Fig. 10 is a schematic view of a STM of the present invention. In Fig. 10, 201 is a silicon substrate on which cantilever type probe of the present invention is formed. 205 is piezoelectric element for coarse movement which drives silicon substrate 201 in the z direction. 215 is a driving mechanism which controls movement of piezoelectric element for coarse movement 205 and cantilever type probe 202 close to the sample surface. 203 is sample for observation and 204 is an xy fine movement mechanism which causes sample 203 to move with fine control in the x,y direction.

Motion of the STM is explained as follows:

Cantilever type probe 202 is brought close to a surface of sample 203 so as to put probe 202 under control of piezoelectric element for coarse movement 205 by working approaching mechanism 215 which consists of stage movable in the z direction by hand or by motor.

The approach is halted by monitoring the distance either by using a microscope or the like, or by automatic control using a servo-mechanism to propel cantilever type probe 202 and detecting current flow between the probe and the sample.

At sample 203, tunnel current flowing between sample 203 and the probe (to which a bias voltage is applied by bias circuit 206) is detected by tunnel current detecting circuit 207. Motion of cantilever type probe 202 in the z direction is controlled through z direction servo circuit 210.

That is, by scanning cantilever type probe 202 in the xy direction using xy scanning circuit 209, while controlling cantilever type probe 202 through low-pass filter at z direction by servo circuit 210 so as to keep the mean distance between the probe and the surface of specimen constant, the tunnel current is changed according to the fine unevenness of the sample surface. By monitoring the tunnel current in control circuit 212 and treating it in synchronization to the xy scanning signal, an STM image with a constant height mode is obtained. The STM image is shown on display 214 by image processing, such as two-dimensional FFT.

At that time, if the temperature drift in the apparatus or the unevenness or slope of the surface of sample 203 are large, cantilever type probe 202 cannot follow the change because the stroke of cantilever probe 202 in the z direction is small. Therefore, control is accomplished so as to follow slow motions by passing a signal from tunnel current detecting circuit 207 through driving circuit for z-direction coarse movement 211 by using piezoelectric element for coarse movement and by making feedback of band width 0.01 to 0.1 Hz.

The scanning range of in the xy directions of cantilever probe 202 is narrow. Therefore, observation is made by moving xy fine movement mechanism for sam-

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ple 204 in the xy directions using driving circuit for xy fine movement 213 and by bringing the probe into a desired region.

In this type of STM it is possible to reduce noise induced to the probe and the drawing electrode from driving electrodes and to detect tunnel current with higher S/N values by using a cantilever probe which contains the electrode structure shown in the above Example and the driving method thereof.

Example 8

A recording-reproducing appratus having a plurality of cantilever probes described in any one of Examples 1 to 6 is explained in this Example.

Fig. 11 is a schematic view of a recording-reproducing apparatus of the present invention.

In Fig. 11, 101 is a silicon substrate on which a plurality of cantilever probes of the present invention are provided, 105 is piezoelectric element for coarse movement which can drive the silicon substrate 101 in the z direction, 103 is circular recording medium and 104 is data line comprising recording bits. Recording medium 103 is rotated so as to keep its angular velocity constant by motion (not shown) and data line 104 is recorded concentrically. Cantilever probe 102 and piezoelectric element for coarse movement 105 are constituted so as to be able to move in the radius direction of recording medium 103 by a linear motor movement mechanism (not shown), and can access arbitrary data lines and perform recording-reproducing of data. At that time, access to a desired data line is conducted by position detecting apparatus such as a linear encoder and each of cantilever probes 102 is controlled so as to follow an objective data line.

Recording medium 103 comprises, for example, a thin film having an electric memory effect such as (i) a recording layer comprising an organic compound with a π electron system or chalcogenites and (ii) an electroconductive substrate. Recording is performed by applying voltage exceeding a predetermined threshold between the probe and the electroconductive substrate to cause a characteristic change over a minute region in the recording layer beneath the probe. Reproducing is performed by utilizing the difference of tunnel current flowing between the probe and the recording layer at a recorded portion and an unrecorded portion.

Recording medium 103 includes an epitaxial growth surface of Au or cleavage surface of graphite formed on a substrate having a smooth surface such as glass, mica and the like, and two layers of monomolecular film comprising squarilium-bis-6-octylazulene (SOAZ) provided thereon by the well known Langmuir-Blodgett method.

In this case, when voltage applied between probe and recording layer does not exceed the threshold voltage which causes electric memory effect, for example, tunnel current is less than 10^{-11}A, then the recording layer maintains the OFF-state. On the other hand, when voltage is applied, after applying a pulse voltage with a triangular wave exceeding the threshold voltage, current with 10^{-7}A flows and the recording layer changes into the ON state and recording is performed. When voltage is applied after applying a reverse pulse with triangular wave exceeding the threshold voltage which changes the ON-state into OFF state, the current is less than 10^{-11}A and the recording layer changes into the OFF-state and recording data is erased.

Next, motion of recording-reproducing apparatus is explained.

Recording is performed by moving the piezoelectric element for z-direction coarse movement 105 and cantilever probe 102 to a recording position using the movement mechanism and by applying voltage exceeding the threshold voltage to recording medium 103. At that time, bias voltage is applied to recording medium 103 using bias circuit 106 and probe 7 is kept at the distance which allows tunnel current to flow to recording medium 103.

The approach is conducted by bringing probe 7 close to the recording medium using the electric element for z-direction coarse movement 105, followed by drawing each probe into tunnel region using the plurality of cantilever probes 102.

The drawing of probes is conducted by performing feedback of tunnel current, which is detected by tunnel current detecting circuit 107 corresponding to each probe, through z-direction servo circuit 110 of each cantilever probe 102, while controlling the distance between each probe and recording medium to be constant. A low-pass filter is provided in z-direction servo circuit 110, cut-off frequency is selected not to follow a data signal, but to follow the surface undulation of recording medium 103 and the average distance between probe and recording medium is controlled to be constant.

Recording is performed by sending a recording signal to pulse applying circuit 108 from controlling circuit 112 and applying it to each probe as pulse voltages.

At that time, driving voltage for cantilever probe 102 is kept constant while applying pulse voltage by providing hold circuit in z-direction servo circuit 110 to prevent the change of the distance between probe and recording medium caused by pulse application.

Reproducing is performed by moving the probe above a desired data line by using the movement mechanism and by detecting the amount of the change of tunnel current between the probe and the surface of recording medium 103 in a recorded portion and an unrecorded portion by using the probe.

In a case of recording data line, only position detection is made by the position detecting apparatus in the movement mechanism. Therefore, data line is recorded in a finely undulated state by influence of temperature drift of the apparatus and vibration from outside. In a case of reproducing data line, the same influence as above is affected. So, the probe cannot be moved above the data line, only by using position detection of position detecting apparatus in movement mechanism and S/N

at data reproduction tends to decrease.

Then, cantilever probe 102 is controlled in the direction perpendicular to data line so as to be able to reproduce, following the data line when the probe is moved above a desired data line by using movement mechanism.

Each of cantilever probes 102 is controlled by track servo circuit 109 so as to make the reproducing signal of data line from tunnel current detecting circuit 107, maximum. Reproducing signal of data line from tunnel current detecting circuit 107 is treated in controlling circuit 112, which makes reproducing possible.

Erasing is performed by moving the probe above the data line to be deleted in the same manner as in a case of recording, and by applying erasing pulse voltage opposite to recording pulse voltage by pulse applying circuit 108.

At that time, the distance between probe and recording medium is kept constant by hold circuit in z-direction servo circuit 110.

In this Example, the present invention is explained using circular recording medium. But recording-reproducing may be performed by using flat recording medium and moving cantilever probe relative to recording medium using XY movement mechanism.

In this type of recording-reproducing apparatus, it is possible to reduce noise induced in the probe and drawing electrode from the driving electrode by using the same electrode structure of probe and the same driving method as in the above Example, and to obtain reproducing signal with higher S/N.

As described above, it is possible to reduce noise induced to the probe and drawing electrode from driving electrode and to detect tunnel current with higher S/N by providing a shielding electrode between the driving electrode, and drawing electrode and probe in the cantilever probe having piezoelectric bimorph structure.

It is also possible to reduce noise induced to the probe and drawing electrode from the driving electrode and to detect tunnel current with higher S/N by using a driving method, in which the driving electrode located at the side of the probe and drawing electrode is made common electrode and the potential is kept at ground potential in the driving circuit.

A typical STM apparatus employing a recording layer with electric memory effect is disclosed in Application Serial No. 07/136,728, filed December 22, 1987 (corresponding to EP-A-0272935).

This invention is not to be limited to the concept as set forth in the following claims.

Claims

1. A cantilever probe comprising a piezoelectric bimorph cantilever comprising piezoelectric material (5) provided between driving electrodes (2a,2b;3;4a,4b) for driving the cantilever, a probe (7) formed on the cantilever, and a drawing electrode (6) for the probe (7) formed on the cantilever;

   characterised in that:

   a shielding electrode (11) is provided on the cantilever for electrically isolating the drawing electrode (6) and the probe (7) from the driving electrodes, and

   means (3) are provided for earthing the shielding electrode.

2. A cantilever probe according to Claim 1, wherein the shielding electrode (11) is provided between (a) the piezoelectric bimorph structure and (b) the probe (7) and the drawing electrode (6).

3. A cantilever probe according to Claim 1, wherein said drawing electrode (6) is provided on the same plane as said probe (7) on said cantilever, and a part (2a,2b) of said driving electrodes is provided on said plane, said shielding electrode (11) being provided between said probe (7) and said drawing electrode (6), and said part (2a,2b) of said driving electrodes.

4. A cantilever probe according to Claim 1, wherein each of said driving electrodes (2a,2b;3;4a,4b) is divided in the direction of the width of said cantilever, and said shielding electrode (11) is provided on the same plane as the driving electrodes (2a,2b) which are located in the middle of said cantilever.

5. An information processing apparatus including a cantilever probe according to any one of Claims 1 to 4.

6. A scanning tunnel microscope including a cantilever probe according to any one of Claims 1 to 4.

Patentansprüche

1. Ausleger-Sonde mit einem piezoelektrischen Bimorph-Ausleger mit

   - zwischen Treiberelektroden (2a, 2b; 3; 4a, 4b) vorgesehenem piezoelektrischem Material (5) zum Treiben des Auslegers,
   - einer auf dem Ausleger gebildeten Sonde (7) und
   - einer auf dem Ausleger gebildeten Zieh-Elektrode (6) für die Sonde (7),

   dadurch gekennzeichnet, daß

   - auf dem Ausleger eine Abschirmelektrode (11) zum elektrischen Isolieren von Zieh-Elektrode (6) und Sonde (7) gegenüber den Treiberelek-

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troden vorgesehen ist und
- Mittel (3) zum Erden der Abschirmelektrode vorgesehen sind.

2. Ausleger-Sonde nach Anspruch 1, bei der

- die Abschirmelektrode (11) zwischen (a) der piezoelektrischen Bimorph-Struktur und (b) der Sonde (7) und der Zieh-Elektrode (6) vorgesehen ist.

3. Ausleger-Sonde nach Anspruch 1, bei der

- die Zieh-Elektrode (6) auf derselben Ebene wie die Sonde (7) auf dem Ausleger vorgesehen ist und
- ein Teil (2a, 2b) der Treiberelektroden auf dieser Ebene vorgesehen ist, wobei die Abschirmelektrode (11) zwischen Sonde (7) und Zieh-Elektrode (6) und besagtem Teil (2a, 2b) der Treiberelektroden vorgesehen ist.

4. Ausleger-Sonde nach Anspruch 1, bei der

- jede der Treiberelektroden (2a, 2b; 3; 4a, 4b) in Breiten-Richtung des Auslegers unterteilt ist und
- die Abschirmelektrode (11) auf derselben Ebene wie diejenigen Treiberelektroden (2a, 2b), welche in der Mitte des Auslegers angeordnet sind, vorgesehen ist.

5. Informationsverarbeitungsapparatur mit einer Ausleger-Sonde nach einem der Ansprüche 1 bis 4.

6. Rastertunnelmikroskop mit einer Ausleger-Sonde nach einem der Ansprüche 1 bis 4.

Revendications

1. Sonde en porte-à-faux comprenant un élément en porte-à-faux bimorphe piézoélectrique comportant un matériau (5) piézoélectrique disposé entre des électrodes (2a,2b;3;4a,4b) d'attaque pour attaquer l'élément en porte-à-faux, une sonde (7) formée sur l'élément en porte-à-faux, et une électrode (6) d'extraction destinée à la sonde (7) formée sur l'élément en porte-à-faux ;

caractérisée en ce que :

une électrode (11) de blindage est prévue sur l'élément en porte-à-faux pour isoler électriquement l'électrode (6) d'extraction et la sonde (7) des électrodes d'attaque, et
des moyens (3) sont prévus pour relier à la masse l'électrode de blindage.

2. Sonde en porte-à-faux selon la revendication 1, dans laquelle l'électrode (11) de blindage est disposée entre (a) la structure bimorphe piézoélectrique et (b) la sonde (7) et l'électrode (6) d'extraction.

3. Sonde en porte-à-faux selon la revendication 1, dans laquelle ladite électrode (6) d'extraction est disposée dans le même plan que ladite sonde (7) sur ledit élément en porte-à-faux, et une partie (2a, 2b) desdites électrodes d'attaque est disposée dans ledit plan, ladite électrode (11) de blindage étant disposée entre ladite sonde (7) et ladite électrode (6) d'extraction, et ladite partie (2a,2b) desdites électrodes d'attaque.

4. Sonde en porte-à-faux selon la revendication 1, dans laquelle chacune desdites électrodes (2a,2b; 3;4a,4b) d'attaque est divisée dans la direction de la largeur dudit élément en porte-à-faux, et ladite électrode (11) de blindage est disposée dans le même plan que les électrodes (2a,2b) d'attaque qui se trouvent au milieu dudit élément en porte-à-faux.

5. Appareil de traitement d'informations comportant une sonde en porte-à-faux selon l'une quelconque des revendications 1 à 4.

6. Microscope à effet tunnel à balayage comportant une sonde en porte-à-faux selon l'une quelconque des revendications 1 à 4.

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FIG. 1 (a)

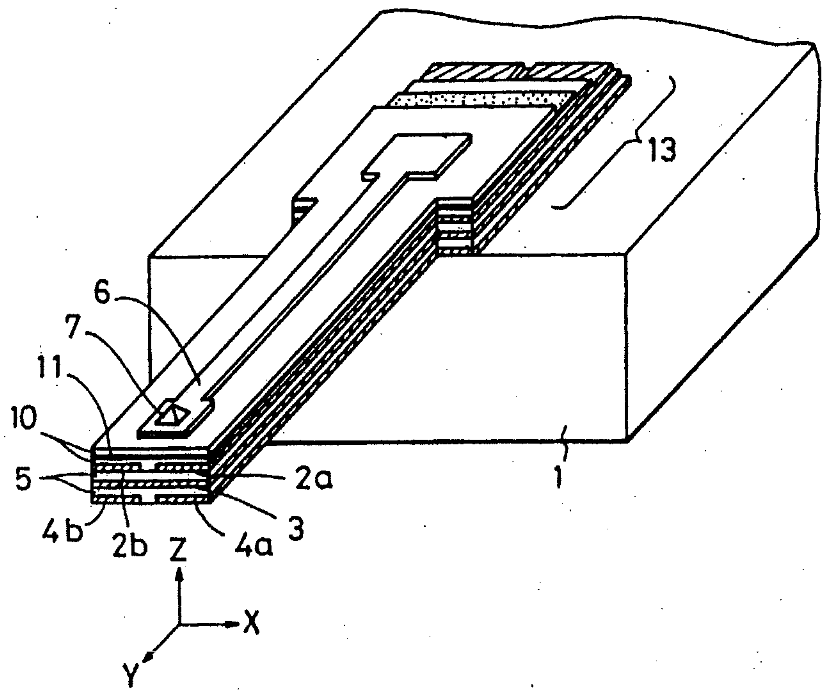

FIG. 1 (b)

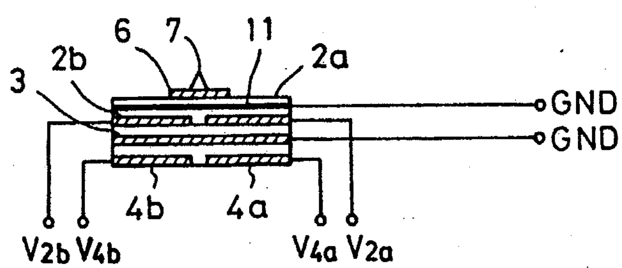

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FIG. 2

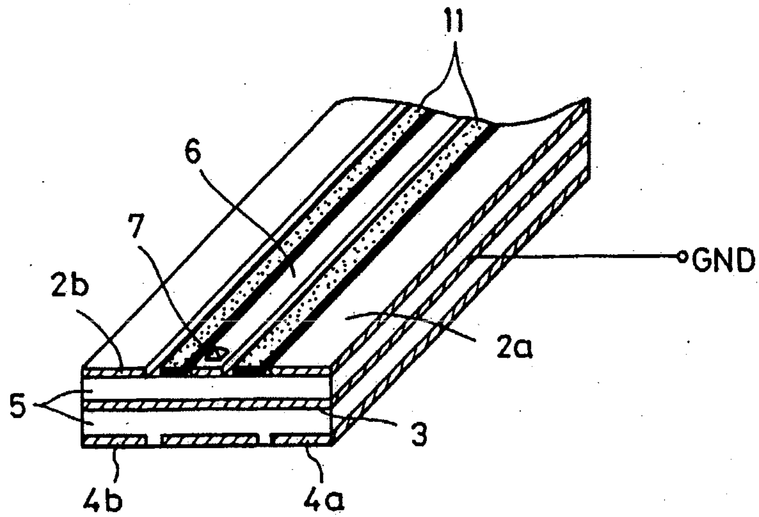

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FIG. 3(a)

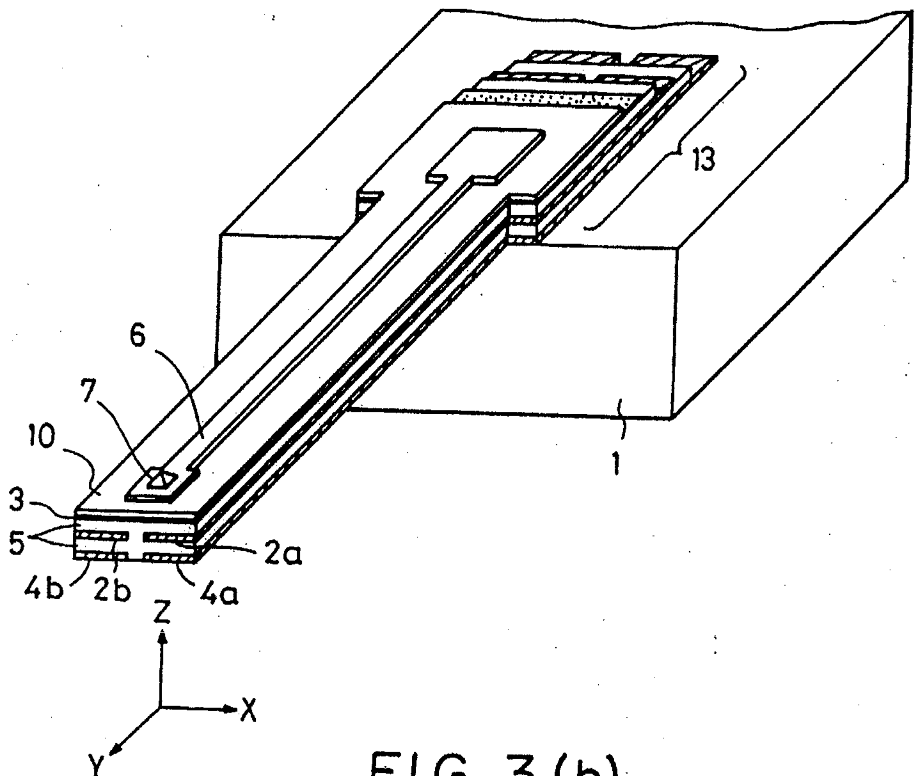

FIG. 3(b)

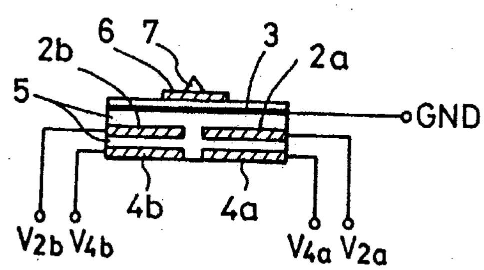

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FIG. 4 (a)

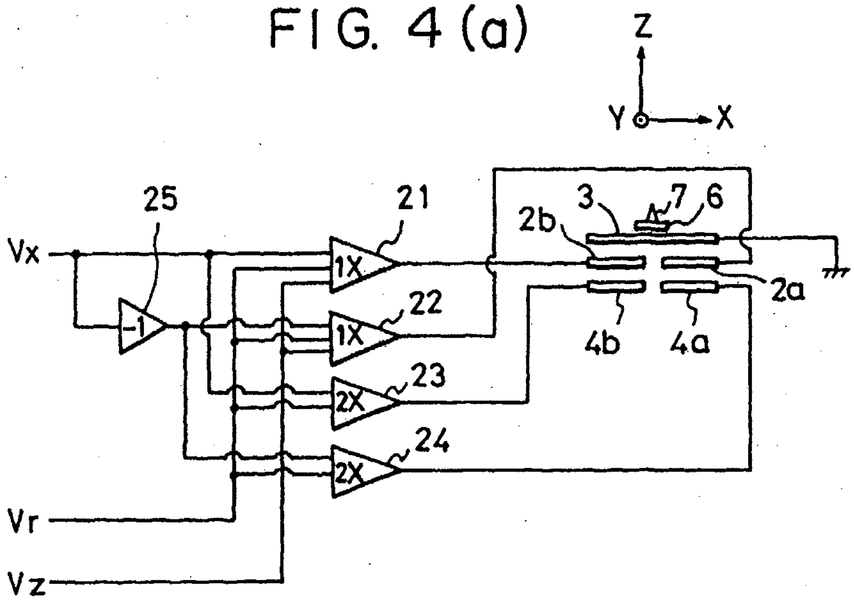

FIG. 4 (b)

	2a	2b	4a	4b
X DIRECTION	− Vx	+ Vx	− 2Vx	+ 2Vx
Y DIRECTION	+ Vr	+ Vr	+ 2Vr	+2Vr
Z DIRECTION	−Vz	−Vz	0	0

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FIG. 5(a)

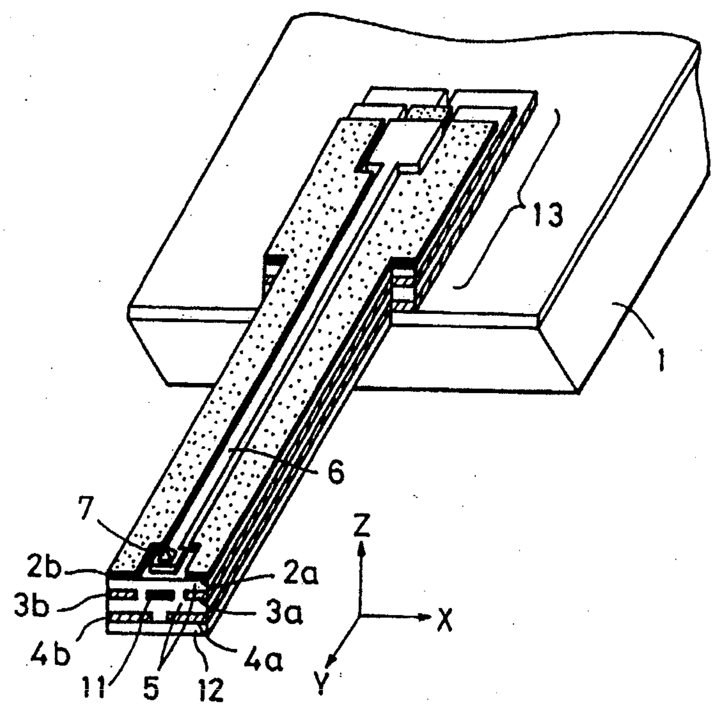

FIG. 5(b)

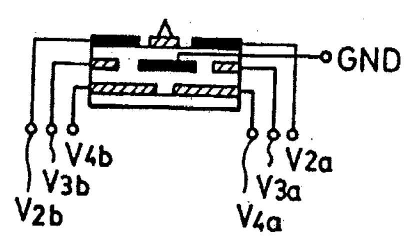

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FIG. 6

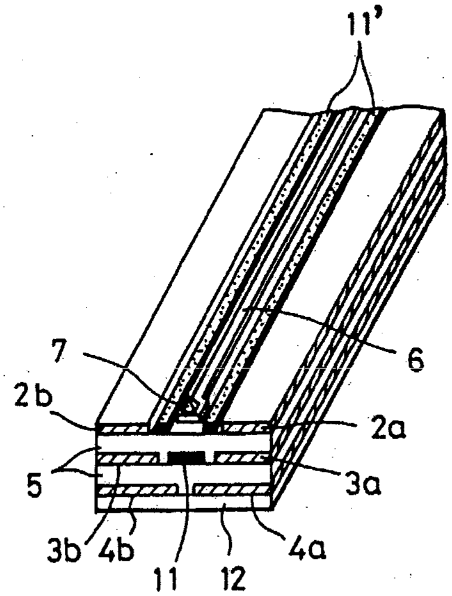

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FIG. 7(a)

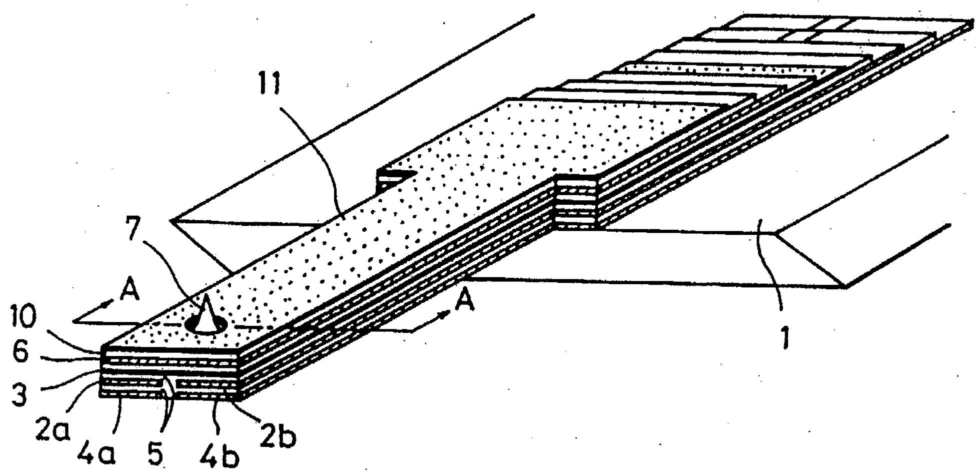
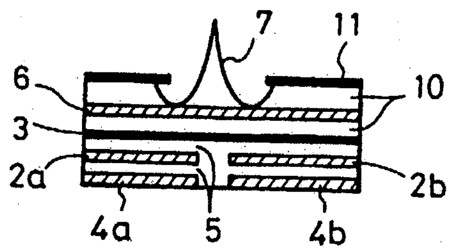


FIG. 7(b)

(A-A SECTIONAL VIEW)



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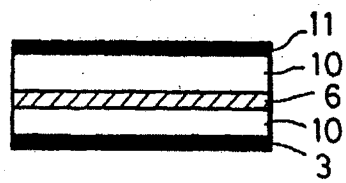

FIG. 8(a)

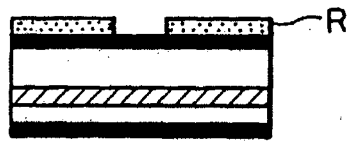

FIG. 8(b)

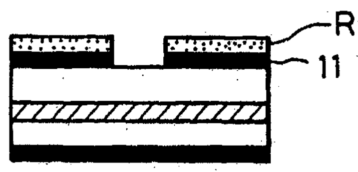

FIG. 8(c)

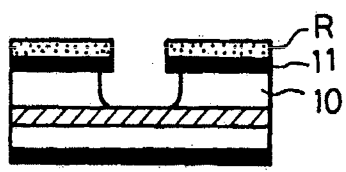

FIG. 8(d)

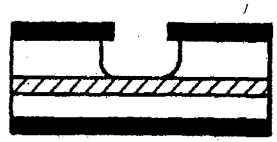

FIG. 8(e)

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FIG. 9

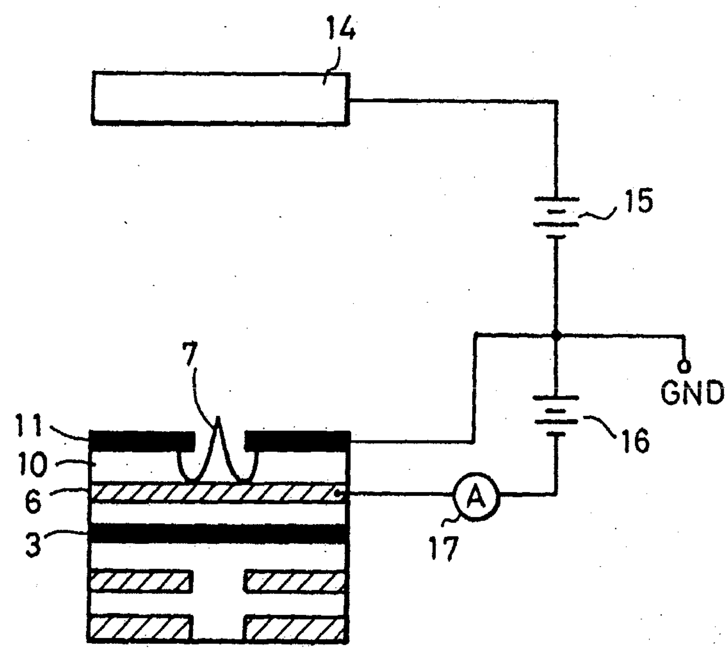

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FIG. 10

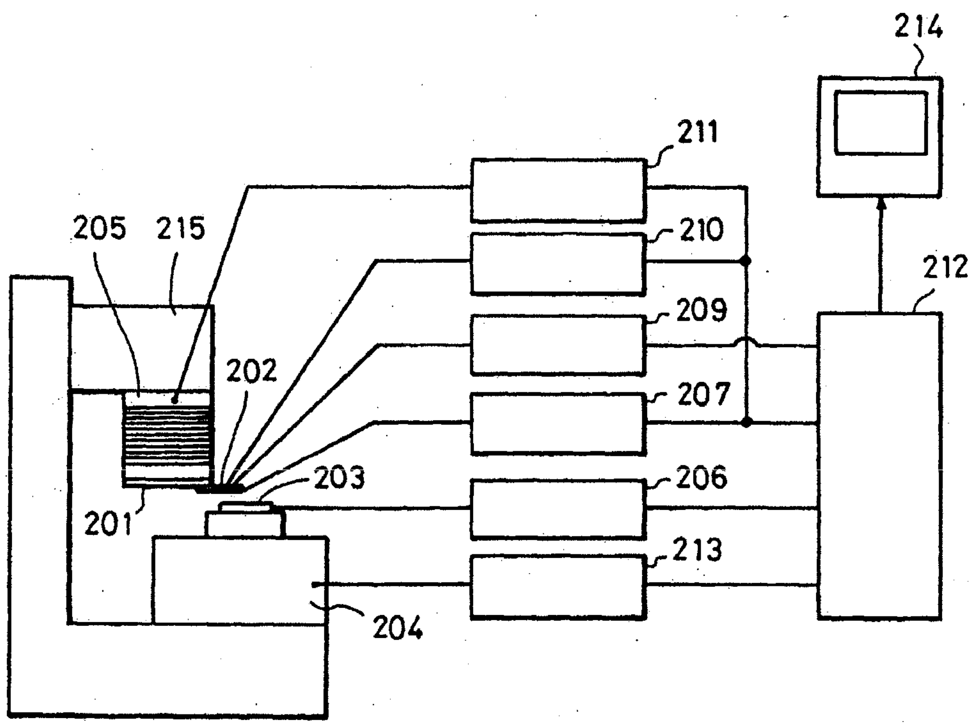

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FIG. 11

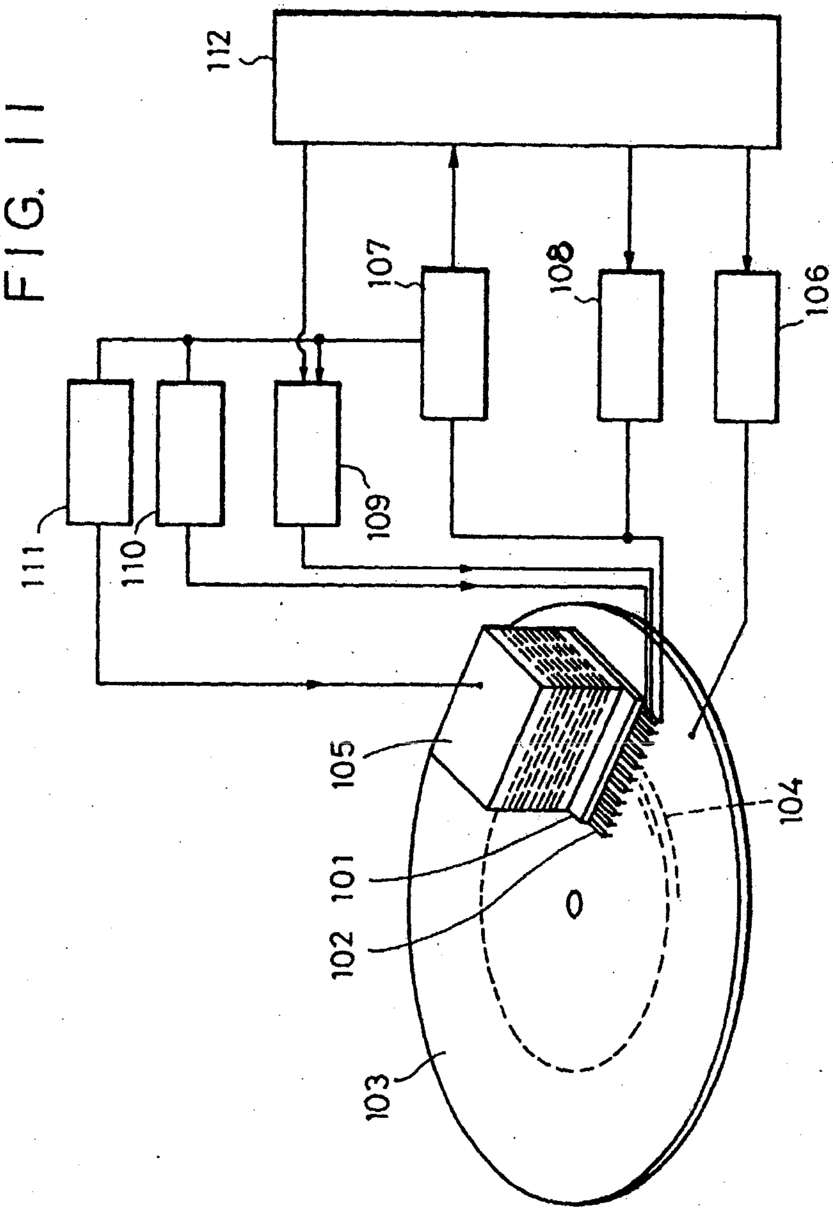

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FIG. 12(a)
PRIOR ART

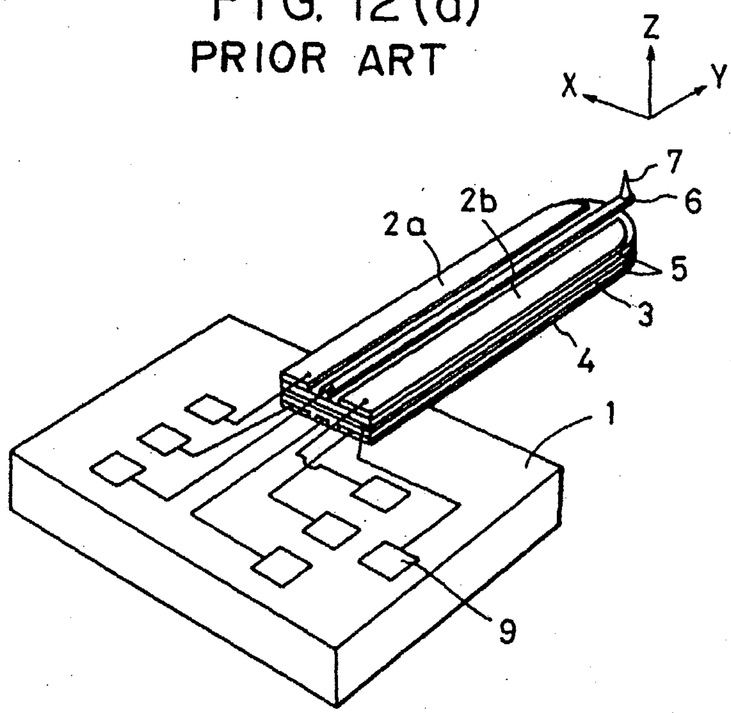

FIG. 12 (b)
PRIOR ART

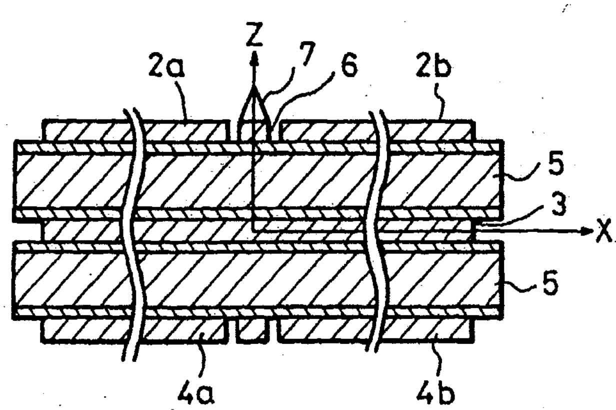

FIG. 13(a)
PRIOR ART

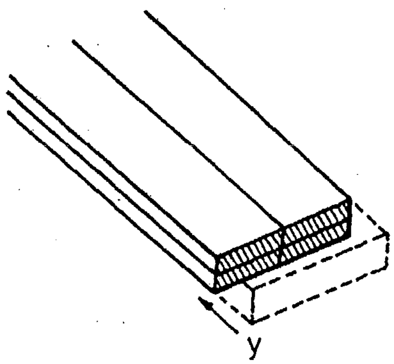

FIG. 13(b)
PRIOR ART

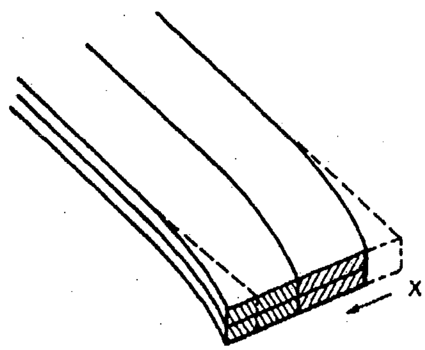

FIG. 13(c)
PRIOR ART